EDITORS

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NITROGEN IN THE ENVIRONMENT

SOURCES, PROBLEMS, AND MANAGEMENT

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About the Editors

Dr. Jerry Hatfield received his Ph.D. from Iowa State University in 1975 in the area of Agricultural Climatology and Statistics. From 1975 through 1983 he was the Biometeorologist at the University of California-Davis and from 1983 through 1989 Research Leader at the Agricultural Research Service (ARS) of the Unites States Department of Agriculture (USDA) Plant Stress and Water Conservation Laboratory in Lubbock, Texas. Since 1989 he has served as the Laboratory Director of the USDA-ARS National Soil Tilth Laboratory (NSTL) in Ames, Iowa. Dr. Hatfield has been responsible for the development of the scientific program in the NSTL and the management of a multi-agency, multi-location environmental quality program to assess the impact of farming practices on water quality. He has developed several watershed scale projects to address concerns about the spatial and temporal impacts of farming practices on environmental quality. He has been responsible for the evaluation of the impact of farming systems on both water quality and air quality. His research interests focus on the interaction of water, nutrients, carbon, and light in the response of crops to management systems across varying landscapes. His research on water quality has been directed toward the evaluation of role of cropping systems on seasonal water use patterns and the impact of these on movement of pesticides and nutrients. In the air quality area he has focused on the role of soil management on emission of greenhouse gases and ammonia and the dynamics of carbon dioxide and water vapor exchanges in crop canopies. He is the Lead Author on the agriculture chapter in the "Synthesis and Assessment Product 4.3, The Effects of Climate Change on Agriculture, Land Resources, and Biodiversity" as part of the Climate Change Assessment Program of the United States. He served as President and Editor-in-Chief of the American Society of Agronomy and is a Fellow of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America and a 1997 recipient of the A.S. Flemming Award for Outstanding Federal service and an ARS Outstanding Scientist of the Year in 1999 and the US Presidential Rank Award for Superior Service in 2006. He is the author over 350 referred publications and the editor of ten monographs.

Dr. Ronald F. Follett received his Ph.D. degree as a Soil Chemist from Purdue University in 1966. He served in the US Army from 1966 to 1968 where he attained the rank of Captain and later the rank of Major in the US Army Reserves. In 1968 he joined the USDA-ARS. For the past 21 years he has been a Supervisory Soil Scientist and Research Leader in the ARS Soil-Plant-Nutrient Research Unit in Fort Collins, Colorado. He previously served 10 years in ARS Headquarters in Beltsville, Maryland as National Program Leader for "Soil Fertility and Plant Nutrition", "Stripmine Reclamation", and "Environmental Quality"; and earlier in his career was a Research Soil Scientist with ARS in Mandan, ND and Ithaca, NY. Dr. Follett is a Fellow of the Soil Science Society of America, American Society of Agronomy, and the Soil and Water Conservation Society. He was awarded the USDA Distinguished Service Award in 1984 and 1992 and the USDA Superior Service Award in 2000. He received the US Presidential Rank Award for Superior Service in 2004. More recently he received the ARS Northern Plains Area Senior Scientist Award (2005), and in 2007 he received an Innovative Cropping Systems Team Award presented by No-Till Farmer's Magazine. Dr. Follett is currently Lead Scientist of GRACEnet (Greenhouse Gas Reduction through Agricultural Carbon Enhancement network) and co-ordinates related research from over 30 locations. He organized and wrote the ARS Strategic Plans for both Groundwater Quality Protection – Nitrates' and Global Climate Change – Biogeochemical Dynamics'. Dr. Follett has co-authored, edited, or co-edited 14 books. His 3001 scientific publications are on nutrient management for forage production, soil-N and C-cycling, groundwater quality protection, global climate change, agroecosytems, soil and crop management systems, soil erosion and crop productivity, plant mineral nutrition, animal nutrition, irrigation, and drainage.

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Nitrogen in the Environment: Sources, Problems, and Management
J.L. Hatfield and R.F. Follett (Eds)

Chapter 1. The Nitrogen Cycle, Historical Perspective, and Current and Potential Future Concerns

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Nitrogen (N) along with carbon and oxygen is the most complex and crucial of the elements essential for life. Supplementing grain and grass forage crops with organic and inorganic N fertilizers has long been recognized as a key to improving crop yields and economic returns. Globally, N fertilizer is largely used for cereal grain production and accounts for an estimated 40% of the increase in per capita food production in the past 50 years (Mosier et al., 2001). Smil (2001) estimates that N fertilizer supplies up to 40% of the world's dietary protein and dependence on N from the Haber–Bosch process will increase in the future. Nitrogen compounds also have been recognized for their many potential adverse impacts on the environment and health (Keeney, 2002).

From 1850 to 1980, biological scientists concentrated on unraveling the biological and physical–chemical intricacies of N. We now know the paths of its comings and goings, the route it takes as it moves, at rates varying from milliseconds to centuries, through nature's compartments (atmosphere, soil, water, and living matter), and the interactions of N with various elements. We know as well its oxidation/reduction status under varying environmental conditions. But nature, in its clever way, has kept science from tracking precisely the actual ledger of this whimsical element and of predicting the impact of N on the environment when it accumulates at levels far above that for which stable ecosystems have adapted.

Many ecological problems occur when N is separated from its most common partner, carbon (Asner et al., 1997; Keeney, 2002; Townsend et al., 2003). Nitrification, denitrification, nitrous oxide formation, leaching of nitrate, and volatilization of ammonia are fates of the mobile N atom. Environmental effects vary with the N form. The atmosphere might receive more nitrous oxide than it can assimilate, resulting in stratospheric ozone destruction, while nitrous oxide and ammonia are greenhouse gases. Combined N in the atmosphere and precipitation fertilizes natural ecosystems resulting in lowered biodiversity, stress, and N leakage, while acidity from nitric oxide and ammonia oxidation depletes ecosystems of bases and results in acid lakes and streams and declining health of forests.

Lakes, coastal waters, and estuaries, overloaded with biologically available N, produce organic materials in abundance. The N atom gets connected to carbon, but the unwanted effects of excess growth and subsequent decay create anaerobic conditions. Nitrogen is widely regarded as responsible for the hypoxia (low oxygen) zone in the Gulf of Mexico that concerns ecologists and conservationists as well as those financially dependent on fish and shrimp catches. Decaying organic matter removes oxygen, changing the ecology and productivity of the bottom waters in a large area of the Gulf. Productive agricultural regions of the Central US are the major source of the nitrate to the Gulf.

Can the N cycle be managed to minimize the problems N generates? Given the world's needs for food – the great ability of annual grains to produce the needed food (and animal feed) – and the economic returns from N fertilizers, change on the larger scale will be slow and requires policy changes as well as economic assessments that include externalities. The United Kingdom and Western Europe have adopted strict manure and fertilizer application regulations with stiff fines for failing to adhere to the regulations. Other countries, including the United States and Canada, have relied on education and demonstration programs to lessen environmental effects from excess N fertilizer use. The changing economics of N use and return from commodity crops may also play a role. Iowa and some other states in the United States have had some modest success at decreasing N fertilizer use through research and education projects. However, ground and surface water quality measurements in Iowa have shown little long-term change in nitrate concentrations illustrating again the problems of second guessing the N cycle.

The solutions to the issues on environmental effects of N will involve looking beyond the edge effects to redesigning agriculture in ways that will tighten up the N cycle and that will provide for N sinks such as grasslands and wetlands. To do this, policies will need to be developed that assure the farmer and the public that such measures will not cost productivity, and that a redesigned agriculture can provide for future food needs. Turning back is not possible. The road ahead will demand a level of innovation of agricultural research and development of new agriculture systems.

1. THE NITROGEN CYCLE

AZOT, the German word for N, was the subject of ancient philosophers. AZOT is believed to be formed from the ancient scientific alphabets, A (the beginning of scientific Latin, Greek, and Hebrew) and zet, omega, and tov, the last letters of these alphabets. The term "saltpeter" came from the association of nitrate salts with the salt of the earth or the salt of fertility. Potassium nitrate was manufactured for gunpowder in the 14th century. By the 1650s Johannes Rudolph Glauber spoke of "nitrum as the 'soul' or 'embryo' " of saltpeter. He states, "It is like a wingless bird that flies day and night without rest; it penetrated between all the elements and carries with it the spirit of life–from nitrum are originated minerals, plants and animals. (It) never perishes; it only changes its form; it enters the bodies of animals